THE IMPROVEMENT AND MANAGEMENT OF "SLICK-SPOT" SOIL

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INTRODUCTION

A vision of desolation arises immediately in the minds of soil scientists when the word "alkali" is mentioned. They picture a barren tract of land devoid of vegetation with a dispersed surface.

Alkali has prevented the cultivation of vast areas of land, and has caused the abandonment of many acres of once-productive land (7, 20).

Soil alkali lowers the value and productivity of extensive land areas in the United States. It is an especially serious problem to irrigation agriculture. In the United States, Bower and Firemen (7) reported about 25 percent of the 29 million acres of irrigated land and less extensive acreages of non-irrigated and pasture lands to be affected by salinity and alkalinity. These figures indicate the importance of the problem in the United States.

Centuries ago, Arab tribesmen noting that alkali soils looked like wood ashes, called them by the Arabic term for ashes, alkali. In Russia the terms solonetz, solonchak, and soloth are used to describe saline or alkali soils (29). Solodized-Solonetz and Solonetz soils collectively have been called natric soils due to their characteristic B horizons which have been termed natric horizons in the new U.S. Soil Classification System (7th Approximation) (52).

Saline and alkali soils have been caused by soluble salts consisting mainly of sodium, magnesium, calcium, chloride, and sulfate and secondarily of potassium, carbonate, bicarbonate, and sometimes nitrate and boron (7, 54).

The alkali soils of this study owe their distinctive morphology and character to excessive exchangeable sodium. Soluble salts high in sodium harm plants by increasing the salt content of the soil solution and the percent saturation of exchangeable sodium on the exchange complex. When the soluble

soil constituents consist largely of sodium salts, the metallic cations other than sodium leach more readily, increasing the percentage saturation of exchangeable sodium on the exchange complex, producing a dispersed poorly structured soil.

In humid climates poorly structured, high-sodium soils occur in small areas. These soils, called "alkali spots" or "slick spots", occur throughout eastern Kansas and adjacent states. They are easily recognized by their white or light-gray color, their dispersed and crusted surface structure, and their sparse vegetation.

These spots occur chiefly in depressions, at the sides or heads of draws, on the sides and at the bottoms of small slopes and sometimes on level land. They vary greatly in size, chemical composition, and physical properties. Formation of these spots generally has been attributed to lateral and vertical water seepage, to high water tables, or to restricted drainage.

The objectives of this study were 1) to determine the chemical properties of a "slick-spot" soil, 2) determine its classification and 3) suggest practical and economical methods of amelioration that may be recommended to farmers. Therefore the cheapest and most widely applicable treatments were used in the study.

REVIEW OF LITERATURE

Alkali and it's formation

The cause of soil alkali is not easily explained. Opinions differ as to its mode of formation. The many different salts that are involved, each with its own properties; the different soils, all with different textures and composition; the complex reactions between the salts in the soil and the plants growing on it; and the economic aspects involved in reclamation of alkali are

as difficult to solve as any problem in agricultural science.

Saline and alkali soils in the United States, Europe, and Canada have been studied for almost a century. Hilgard, Gedroiz, Hissink, de Sigmond, and Kelley are outstanding investigators in this field, having made basic contributions to our knowledge of genesis, classification, and methods of reclamation of alkali soils (59).

Genesis

Several theories have been advanced regarding the origin of alkali soils, the more important of which are mentioned here.

Hilgard (22) first related origin of soil alkali to primary-minerals weathering in rocks. All soils consist largely of weathered-rock particles and almost all rocks are rich in alkali salts. In arid regions evaporation and lack of leaching leaves most of the salts on the surface where their presence causes soil dispersion and poor structure. A large portion of these salts are leached and carried out of most of the humid region soils. Glinka (17, 18) also supported this theory.

Soil parent material is the most probable source of alkali salts in soils. Kelley (29) stated that the source of alkali was secondary deposits, such as shales, sandstones, glacial and windborne materials, and unconsolidated alluvium of various geological ages which became the parent material of the present soils. This theory is held by many others including Norton and Bray (34). Similarly, Drosdoff, as reported by Wilding et al. (60), theorized that the weathering of sodium feldspars in situ was the source of sodium in the solonetzic soils of Illinois. A combination of these theories with some modification also is held by the U.S. Salinity Laboratory staff (54).

Wilding et al. (60) stated that the solonetzic soils of southern Illinois were due to weathering of composite Farmdale and Peorian loess. They postulated

that differential redistribution of soluble products of weathering was responsible for extractable sodium accumulations in Illinois solonetzic soils.

Fehrenbacher et al. (12) outlined the genesis of Illinois solonetzic soil formed in nearly level fields. Concentrations of sodium were explained by the permeability of the old soil that had developed in the glacial till before loess was deposited. They found that till underlying natric[1/] soils was four or five times more permeable than the underlying associated non-natric soils. In the early stages of soil development, downward-percolating water or the moisture streamlines were channeled through this permeable till causing the soluble products of weathering to be concentrated in the lower part of the loess overlying this permeable till (Figure 1, initial stage). Because of low carbon-dioxide pressures at this depth and soil drying in late summer, calcium and magnesium precipitated and formed carbonate concentrations increasing the proportion of sodium on the exchange complex of the soil.

With increasing sodium, the B horizon became more highly saturated with sodium, more dispersed and less permeable. The B horizon eventually may be as little as one-seventeenth as permeable as the B of adjacent soils.

Once this condition develops, the natric soil wets up slowly and infrequently. With the resulting moisture gradient, water moving downward from the surface laterally from wetter associated soil is intercepted, concentrating sodium in the clay. Repeated wetting and drying cycles cause the dispersed clay to migrate both laterally and upward, so that the B horizon is shallower than in the associated normal soil. As the B horizon of the natric soil becomes less permeable more downward moving water is channeled to and through the

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[1/] Natric is the term applied to alkali soils that have a characteristic (columnar or prismatic) B horizon which has been termed a natric horizon in the new U.S. Soil Classification System (7th Approx.) (53).

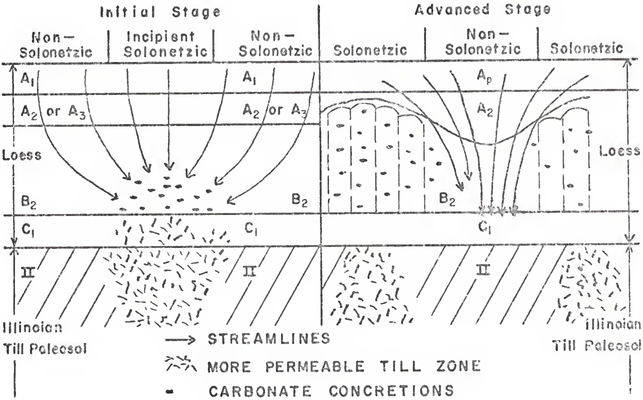

Fig. 1. Schematic diagram of moisture streamlines during initial (left) and advanced (right) stages of solonetzic soil development.

adjacent non-natric soil (Figure 1, advanced stage).

Seawater spray and flooding at high tides are known to cause alkali soils along the sea coasts (1). Russel (48) reported that all of Iraq was once covered by a great sea whose sediments later consolidated to form shales, limestones, and sandstones highly impregnated with salts. Similar conditions occurred in the United States (20, 48).

Vilensky (58) suggested that salt residue that precipitated from melt waters of the last glaciation caused soil salinity.

Robinson (46) reasoned that a rise in the level of salt-bearing ground water could cause salinification. This may take place naturally in some places, but most frequently occurs under inadequate drainage or improper management of soils or irrigation water.

Ahi (1) reported that the water table of the San Joaquin Valley of California once was 65 feet below the surface and the soil was practically free of salts. As a result of irrigation without adequate under-drainage the water table rose to 2-3 feet below the surface and the soils became affected with alkali.

Sandoval et al. (49), (50) and Benz et al. (6) reported that naturally high water tables caused the salinity of 400,000 acres of non-irrigated semi-arid to sub-humid land in the Red River Valley of North Dakota.

Bower and Fireman (7) stated that restricted drainage caused either by a high water table or low permeability may contribute to the salinization of soils. Usually a high water table occurs in low lands as a result of excessive runoff from the adjoining higher land.

Whenever surface or subsurface drainage is restricted, high water tables often result. Then if water or soil is high in alkali salts, these salts remain to cause saline and alkali conditions when the water is removed by

evaporation or transpiration (7, 20, 33, 48).

Chemical properties

Accumulation of soluble salts affects the chemical, physical, and microbiological properties of the soils. These transformations were completely overlooked until the second decade of this century when Gedroiz and Hissink began to study them as reported by Kelley (29).

Although Way (1850), the discoverer of chemical base exchange, and various other investigators of the last half of the nineteenth century, as reported by Kelley (29), showed that base exchange took place in soils upon adding a solution of various salts, it was the twentieth century before it was associated with alkali soil. Hissink (1907) pointed out that base exchange was probably involved with chemical transformation in the wet soils along the coast of Holland (29). Gedroiz (1912) showed that base exchange played an exceptionally important role in the chemical transformations that produced dry-land alkali soils (29).

Kelley (29) stated that normal soils contained little exchangeable K^+ and Na^+ because those monovalent bases are less strongly adsorbed to the clay particles than divalent Ca^{++} and Mg^{++}. Thus if exchangeable Na^+ was adsorbed at any stage in the normal process of soil formation, in a humid climate it soon would be replaced by other cations in solution as a result of weathering, or by H^+ ions of biological origin.

According to Kelley (29), calcium can readily replace exchangeable sodium. In fact, practically all Na^+ that is adsorbed by the soil can be replaced by leaching with a very dilute solution of a calcium salt. Practical advantage can be made of this fact in the reclamation of alkali soils, as will be pointed out later.

Harris (20) and Hilgard (22) considered the soluble carbonates, of all the soluble salts, the most harmful, on account of their soluble action on the organic matter of the soil and the hard crust which they form on the soil. They are, however, not so widespread as the chlorides and sulfates. Calcium and magnesium carbonates are only slightly soluble compared to sodium carbonate, the carbonate that is most harmful to plants.

The relationship of adsorbed ions to alkali soil problems may be briefly summarized by the following schematic reactions: (5)

White alkali soil:	Clay) $\begin{matrix} Na \\ Na \end{matrix}$	$+ \begin{matrix} NaCl \\ Na_2SO_4 \end{matrix}$	flocculation and friability
Black alkali soil:	Clay) $\begin{matrix} Na \\ Na \end{matrix}$	$+ \begin{matrix} NaOH \\ Na_2CO_3 \end{matrix}$	deflocculation and poor physical properties
Reclamation of alkali soils:	Clay) $\begin{matrix} Na \\ Na \end{matrix}$	$+ CaSO_4$	Clay) $Ca + Na_2SO_4$ (leached)

Kelley (29) pointed out that the percent saturation of the base exchange by Na^+ significantly influences the kinds of sodium salts that accumulate. Usually, an alkali soil with a relatively high concentration of sodium carbonate has more adsorbed Na^+ than one which has a high concentration of NaCl or $NaNO_3$. In other words, alkali soils containing Na_2CO_3 (black alkali, according to Hilgard) are likely to be more highly saturated with Na^+ than soils not containing Na_2CO_3.

Although Gedroiz (1912) pointed out that Na_2CO_3 may be formed by hydrolysis of adsorbed Na^+ coupled with the action of CO_2 of the soil, it remained for Cummings and Kelley (1923) to demonstrate that high concentrations of Na_2CO_3 can be formed in this way (29).

Many investigators have found that upon leaching alkali soils, the rate of water penetration diminishes as the salts are leached out. The effect of the

nature of the adsorbed ion on the permeability of water in clays is shown in Figure 2.

The entire physical condition of the soil is changed by the presence of large quantities of all salts, but certain of the alkali salts, particularly sodium, cause complete transformations (29, 41). Poor penetration of water and air becomes especially pronounced when sodium salts comprise a high percentage of the total salts (1, 27, 29, 54).

Baver (5) pointed out that if clays are saturated with a highly hydrated cation (hydration gives sodium a large ionic radius) such as Na^+, the zeta potential (negative-charge potential) will be high. To explain more fully, the clay particles are negatively charged and like negative charges repel each other so that the soil would be dispersed if it were not for the adsorption of flocculating cations such as Ca^{++}. Na^+ fails to neutralize all the negative charges and so the soil is left negatively charged and remains dispersed, or if in the normal use in soils it replaces Ca^{++} in a flocculated soil, it causes dispersion. To sum up, a cation like sodium is called a dispersing agent due to its large hydrated radius plus the fact it has only one plus charge with which to neutralize the negative soil particles. On the other hand, Ca^{++} is a flocculating agent because it has two charges for neutralizing soil particles.

The chief manifestations of salts on the physical condition of the soil according to Harris (20) are: (1) Altering of the colloidal substances; (2) Change in structure and tilth; (3) Formation of a hardpan in the B horizon; and (4) Change in moisture relations.

Where alkali soils high in sodium are leached of other soluble salts, largely calcium, the clay particles become highly dispersed and tend to pass downward with percolating water, thus forming dense subhorizons. Alternate wetting and drying produces peculiar morphological structures in the form of

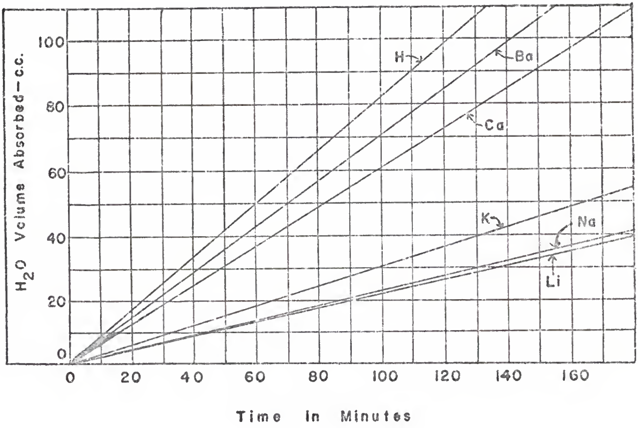

Fig. 2. Effect of the nature of the adsorbed ion on the permeability of water in clays.

columns, prisms, or blocks when dry (29). Such structured soils are called solonetz by Russian soil scientists. These peculiar morphological structures are called natric horizons in the new classification system (52).

Magnesium has been reported by Whittig (59) as the dominant cation on the exchange complex in soils showing typical solonetzic features. Some Canadian soil scientists (4) consider both exchangeable sodium and magnesium responsible for causing the typical morphology of solonetzic soils.

Arshad and Pawluk (4) stated that the National Soil Survey Committee of Canada (1963) defined solonetzic soils as "soils with solonetzic or disintegrating solonetzic B horizons which have an exchangeable base status in which 50% or more is sodium plus magnesium, or which have more than 12% exchangeable sodium, and usually have saline subsoils".

Joffe and McLean (26) reported that at least some of the California alkali soils were not purely sodium soils. Apparently, some of the solonetz had developed either from Ca or Mg-solonchak or as the result of a secondary salinization process.

Kelley (29) showed that effect of exchangeable sodium varies from soil to soil. Bower and Turk (9) reported that an alkali soil from Yakima Valley, Washington lacked excessively poor physical conditions, even though it was almost 50% Na^+ saturated. Kelley (29) believed that this was caused, at least in part, by the kind of clay. Therefore, he concluded that soils do not necessarily return to normal permeability once exchangeable sodium has been replaced with Ca^{++}.

Gedroits, as reported by Harris (20), showed that many of the physical changes ordinarily brought about in soils by salts come from their effect on colloids.

The microbiology of the soil may be markedly influenced by an accumulation

of salts. Greaves (19) reported that monovalent anions are more toxic to soil bacteria than divalent anions.

Unfortunately little is known about the relations between high salt concentrations or exchangeable sodium to bacterial processes.

Kinds of alkali

The classifications of alkali soils into sharply defined categories is as impossible as, for example, a definite separation of sandy loams from fine sandy loams. The usual case is that they merge almost imperceptibly from one to another (29).

Alkali soils have been divided into (a) "white alkali" and (b) "black alkali", depending upon the accumulated salts present. This differentiation was first made by Hilgard (22).

Alkali consists of four principle types of salts, namely, chlorides, sulfates, carbonates, and bicarbonates of the various bases primarily calcium, sodium, magnesium and sometimes potassium. The sulfates and chlorides of alkali show efflorescence (white shiny appearance) during dry periods, as a result of evaporation, on the surface of the soil from which the American term "white alkali" is derived. Where hydrolysis of the sodium clays has formed NaOH and $NaCO_3$ the corrosive action on vegetable matter produces a brown or black deposit on the soil surface, giving rise to the name, "black alkali". Black alkali is more destructive to plants than white alkali (1, 20, 22).

Kelley (29) divided alkali soils into several different categories. The first of these is strongly alkaline alkali soils. These soils contain substantial amounts of soluble carbonate and relatively high concentrations of soluble Na^+. On the other hand, soluble calcium is low in every one of these soils. Accordingly, exchangeable Na^+ was found to comprise 50 or more percent

of the total exchangeable bases (29).

A second category is the moderately alkaline alkali soils. These soils contain but little soluble CO_3^{--}, and the ratio of soluble Na^+ to soluble Ca^{++} is considerably less than in the strongly alkaline soils. Accordingly, exchangeable Na^+ comprises only about 25% of the total exchangeable ions (29).

Third are the alkali soils containing much soluble Ca^{++}. These were practically free from soluble CO_3^{--} and the ratio of soluble Na^+ to soluble Ca was comparatively low. Although these soils contain greater absolute amounts of soluble Na^+ than of soluble Ca^{++} plus Mg^{++}, and some of them contain high concentrations of soluble Na^+, none contains important percentages of exchangeable Na^+. In fact, the percentage Na^+ saturation of the exchange material of these soils is approximately that of dry-climate normal soils (29).

A fourth category is the nonsaline alkali, or solonetz-like, alkali soil. There are a considerable number of relatively small areas of alkali soil in the United States, which have comparatively low concentrations of soluble salts on which the natural vegetation usually fails to grow. The soil profile of some, but by no means all, of these spots closely resembles that described by Russian soil scientists under the name of solonetz (29). This soil will be further described under the Russian solonetz.

Another commendable classification of alkali soil has been made by Russian investigators (1, 29). In this classification, saline and alkali soils are divided into several types, the more common groupings used in the United States are the Solonchak, Solonetz, Solonchak-Solonetz, and the Solodi.

The profiles of Solonchak (saline or white alkali) soils are characterized by an excess of soluble salts and the colloids are saturated with divalent and monovalent cations, primarily Ca^{++}, Mg^{++}, Na^+, and K^+. Excess of soluble salts prevents the hydrolysis of sodium from the exchange complex and keeps the

colloids flocculated. At times the maximum concentration of salts occurs at or near the surface and at other times it is more concentrated at some distance below the surface. The extent of the salts at different depths of the soil, however, depends on the position of the water table, the concentration and composition of the soluble salts, the amount and distribution of the rainfall, and the general character of the soil of the region. The Solonchak soils are not strongly alkaline because the excess of soluble salts prevents hydrolysis of the sodium-bearing complexes (1).

The Solonetz (black alkali) soils are characterized by a low content of soluble salts. The exchange complexes are largely saturated with bases of which sodium constitutes a high percentage. Because of this high percentage of sodium, high alkalinity is developed. The high sodium content causes dispersion of the colloids, therefore, the soil becomes extremely sticky and tenacious when wet and very hard when dry. These soils exhibit subsoil horizons with prismatic, columnar, or blocky-type structure. The unstable soil undergoes rapid degradation under the influence of exchangeable sodium, which is directly or indirectly responsible for the deflocculation of the colloids (1, 12).

Analyses of solonchak-solonetz profiles show that these soils have sustained some leaching, but only enough to cause partial removal of soluble salts. These soils consequently are about half way between solonchak and solonetz soils (18, 29, 47).

Joffe (25) broke the evolution of saline soils into 3 stages. The first stage represents a process of salinization, the accumulation of soluble salts at or near the surface of the soil profile. Such a soil is known as solonchak.

The second stage is a process of desalinization whereby the soluble salts are leached from near the surface to the bottom of the B or into the C horizon, and the exchange complex is subjected to a considerable saturation with Na and

sometimes Mg. This soil is called a solonetz.

The third stage represents a more thorough leaching of the profile, whereby the soluble salts are completely removed from the profile and, as a result of hydrolytic reactions, the silicates are split and SiO_2 is released. This soil attains a somewhat bleached appearance and resembles a podzol. At this stage the soil is known as solodi.

Probably the most widely used alkali-soil classification in the United States today is the one found in the United States Salinity Laboratory Handbook No. 60 (54).

According to this classification a saline soil is one for which the conductivity of the saturation extract is more than 4 millimhos per cm. at 25°C and the exchangeable-sodium-percentage is less than 15. Ordinarily, the pH is less than 8.5. It corresponds to Hilgard's "white alkali" soils and to the "solonchak" of the Russian soil scientists. Owing to the presence of excess salts and the absence of significant amounts of exchangeable sodium, saline soils generally are flocculated and have good permeability.

Saline-alkali is applied to soils having electrical conductivity greater than 4 millimhos per cm. at 25°C and exchangeable-sodium-percentage greater than 15. These soils are formed by the combined processes of salinization and alkalization. Under the conditions of high soluble salts the soils remain flocculated and have pH values generally below 8.5. As long as excess salts are present the appearance of these soils remain similar to those of saline soils.

Nonsaline-alkali is used for soils having exchangeable-sodium-percentage greater than 15 and conductivity of the saturation extract less than 4 millimhos per cm. at 25°C. The pH generally ranges from 8.5 to 10.

These soils correspond to Hilgard's "black alkali" soils and in some cases

to the Russian "solonotz". They often occur in small irregular areas, commonly referred to as "slick spots".

"Nonsaline-alkali soils in some areas of western United States have exchangeable-sodium-percentages considerably above 15, and yet the pH reading, especially in the surface soil, may be as low as 6.0. These soils have been referred to by de Sigmond (1938) as degraded alkali soils. They occur only in the absence of lime, and the low pH results from the presence of exchangeable hydrogen. The physical properties, however, are dominated by exchangeable sodium and are typically those of a nonsaline-alkaline soil." (54).

Reclamation of alkali soils

No single method of reclamation is adapted to all alkali soils due to their multi-varied conditions. Many widely varied factors and conditions must be taken into account before any one or a combination of known corrective measures are adopted. Some of the more important factors that need to be considered to ascertain the feasibility of reclaiming a given alkali soil are: source of the alkali, physical and structural conditions of the soil, depth to the water-table, cost of reclaiming the soil and its subsequent worth, value of crops that can be grown, and a number of other considerations (20, 27). Knowledge of the aforementioned criteria also will help to determine the measures to use in alleviating the alkali problem. The need for an amendment and the kind and amount of amendment to apply is best ascertained by soil tests according to Reeve and Fireman (42).

Verhoeven (56) used salt transfer in soil to evaluate water flow in saline and alkali soils. Richards (43) stated that soil suction and capillary conductivity measurements would be used increasingly to solve agricultural problems relating to the salinization of soils, to the storage or depletion of

water in soil, and to the extraction of water from soil by plant-root systems.

In a broad sense there are three general ways in which alkali lands may be handled in order to avoid, at least partially, the damaging effects of soluble salts. The first of these corrective measures is removal of the damaging salts; the second is a partial conversion of the salts to less injurious forms; and the third, and probably the most important, may be designated as control (32).

Permanent correction or reclamation of sodic (alkali) soil conditions requires removal of excess sodium from the soil and/or conversion into less injurious forms. The most common methods used to free, at least partially, the soil of alkali are: (1) scraping away the surface soil that is high in alkali, (2) flushing the surface soil with water to remove the sodium taken up from the soil particles near the surface, and (3) leaching with water to remove soluble salts (27, 32). If the soil is a "slick-spot" (a type of black alkali) the application of gypsum or other chemicals may be needed to convert part of the alkali carbonates to surfates, thereby reducing the injurious effects of the soluble salts (32, 54).

Inorganic amendments. The application of gypsum can effectively replace Na^+ by Ca^{++}, but since gypsum is only moderately soluble in water, extensive leaching is necessary for replacement to take place. Moreover, where the concentration of soluble Na^+ salts is high, the nature of the equilibrium between soluble and exchangeable Na^+ by Ca^{++} requires the removal of soluble Na^+ by leaching (29, 37).

To obtain adequate drainage sometimes requires tile drain systems (11, 27). Numerous researchers have reported on the benefits of gypsum in alkali soil melioration. Kelley (29) found gypsum to be effective in reclaiming alkali soils. In experiments near Fresno, California, gypsum at the rates of 10, 12, and 15 tons per acre was found to give good results. Several workers at the

California Agricultural Experiment Station (29, 30, 31) showed the benefits to be derived from gypsum. More recently in Illinois (11, 37) gypsum with adequate leaching was found to be very beneficial. Verhoeven (57) found that when gypsum was added before leaching with water, more effective results were obtained in reducing salinization and high sodium content, than if leaching was started prior to the addition of gypsum.

In Russia, adding gypsum to solonetz-type soils under irrigation and dry-land conditions was found to be highly effective in improving sodium-dispersed soils (3). A 10-ton per acre application of gypsum to the Sebree "slick-spot" soils of Idaho increased the infiltration rate from 0.01 inch to 0.10 inch per hour and to 0.22 inch per hour where 20 tons per acre were applied. Where 10 tons of gypsum were mixed to a depth of 4 feet the rate increased to 0.42 inches per hour, the same as the associated Chilcott soil (38).

Padhi et al. (37) in Illinois reported that significant amounts of leachate were collected and sodium was removed from columns of disturbed B_2 horizon of a solonetzic soil treated with 8 tons per acre of gypsum and a combination of 8 tons of gypsum and 5 tons of starch per acre. However, starch alone was ineffective in removing sodium or correcting the physical condition.

Undesirable physical properties of slick-spots in the Platte and North Platte valleys of Nebraska, and at the Agricultural Experiment Station in Vale, Oregon were ameliorated by sulfur and calcium chloride (16, 61).

Sulfur, iron sulfate and alum ($AlCl_3$) produced important chemical changes in a black-alkali soil near Fresno, California (30). These chemicals were effective in alkali reclamation because of the H^+ ions that were formed. The acid formed by the hydrolysis of iron sulfate and alum, or the oxidation of sulfur, dissolved calcium carbonate, and possible other minerals, bringing calcium into solution.

Pronounced beneficial effects were observed on a Fresno-type black-alkali

soil following sulfuric-acid application of 2.85 and 1.42 tons per acre. Greenhouse experiments indicated that improvement of this soil may be expected from applications as low as 0.4 ton per acre (35).

In reclaiming a Hacienda series soil, the application of a heavy irrigation once or twice a week, plus sulfuric acid, sulfur, and gypsum were found to be effective as reported by Overstreet et al. (36).

Organic amendments. It is well known that organic matter plays an essential role in providing soil structure, or tilth that is needed for high fertility. Therefore, manure and other organic residues should improve these poor-tilth soils (39).

Field tests in Oregon (8) on Malheur silt loam with good underdrainage have shown that gypsum and barnyard manure effectively increase infiltration rates. Rinehart (44) obtained similar results on Sassafras loam in New Jersey. Highest infiltration rates were obtained when a combination of gypsum, and manure or other organic materials were used. Johnston and Powers (28), working with eastern Oregon soils, stated that manure alone was ineffective in improving black alkali, although it improved the tilth and permeability.

Levans and dextrins, bacterial metabolic polysaccharides produced in the formation of soil organic matter, are known to improve the aggregating properties of soils (39). Cellulose acetate and carboxymethyl cellulose improve the air-water relationships of soil according to Quastel (39). Quastel's results confirm the findings of Felber (13) that methyl cellulose increases the soil-moisture retention capacity.

Polyelectrolytes. Analysis of the decomposition products of organic materials has shown compounds that appear to be large or complex polysaccharide molecules. The discovery that these specific chemical compounds promoted aggregation has led to the development of a number of synthetic soil conditioners (23). Hedrick and Mowry (21) found that rates of polyelectrolytes up

to 0.1% of the plow depth increased aggregate stability and therefore aeration and percolation. Allison (2) obtained similar results.

When a polyanion such as a hydrolyzed polyacrylonitrile is applied at rates varying from 0.01 to 0.1% to poor-structured soil, the aggregate analysis as determined by wet-sieving is increased, and the working properties are improved along with other factors associated with good tilth (21).

Even though many of the synthetic soil conditioners in the polyelectrolyte field improve soil structure their cost is usually too high for practical application in normal field-scale operation (23).

Deep plowing. Deep plowing to a depth of 30 to 36 inches has been used to reclaim low-producing "slick-spot" soils in the lower Snake River valley of Idaho and Oregon in work reported by Rasmussen (53). In this area the plowing brings up and incorporates naturally occurring gypsum into the surface soil; deep plowing also mixes the clay subsoil with the less clayey topsoil and breaks up a cemented soil layer. Rinehart et al. (45) obtained the same effect by applying gypsum to soils lacking it. Padhi et al. (37) of Illinois found that sodium leached more rapidly from disturbed soil columns and field plots than from undisturbed columns and plots of an Illinois solonetzic soil, especially in the presence of gypsum.

Other amendments. When sodic-alkali soil is leached with low-salt content water, resulting reduced permeability may decrease the rate of reclamation. Increasing the electrolyte concentration of the leachate can materially increase the transmission rate of water according to Reeve and Bower (41). These effects were also shown by Fireman (14), and Fireman and Bodman (15). Quantitative data on the effect of electrolyte concentration on soil permeability were published by Quirk and Schofield (40). They also have pointed out the advantages of using high-salt waters for reclamation purposes. Reeve and

Bower (41) obtained complete reclamation of an experimental soil column with 0.4 feet of Salton Sea water combined with 6.0 feet of Colorado River water in one-tenth the time required for Colorado River water alone.

Regarding reclamation advances, Jenny (24) wrote in 1961, "Today, over three-quarters of a century have elapsed since Hilgard first postulated his reclamation methods. Leaching with or without chemical treatment-depending on local soil conditions is still the key to successful removal of alkali."

Control of alkali soil

An important element of alkali control is the retardation of evaporation. Carter (10) recommended a soil mulch especially on irrigated lands where alkali concentrations are likely to appear. Under the heading of alkali control fall the management practices suggested by Johnsgard (27); (1) Selection of crops or crop varieties that produce satisfactory yields under moderately saline and alkali conditions; replacing wheat with barley, and corn with sorghum or sudangrass, for example. (2) Use of land-preparation and tillage methods that control or remove salinity or alkali; return all crop residues and add additional organic matter such as manure, if practical, particularly to the dispersed-soil areas. (3) Use special planting procedures that minimize salt accumulation around the seed; for example, plant sugar beets on the side of furrow ridges, or ridge over the seed to let high salt contents collect at the surface above the sprouting seeds. (4) Irrigate so as to maintain a relatively high soil-moisture level and at the same time allow for periodic leaching of the soil. (5) Maintain water-conveyance and drainage systems such as tile drains for impervious soils. (6) Use special treatments, such as additions of chemical amendments and organic matter, and grow sod crops to improve structure.

In practical field reclamation of alkali soils, combinations of these preceding ameliorative practices are used.

EXPERIMENTAL PROCEDURE

1965 Field Experiment

A so-called "slick-spot" soil, such as commonly occurs among the soils of eastern Kansas and adjacent states, was chosen for this investigation. The soil was an unnamed, alkali-affected soil occurring on the Kansas State University Agronomy Farm.

There were two mechanical treatments: (1) plowed at 24-inch depth in early spring 1965, (2) plowed at 7-inch depth in fall of 1964. Plate I shows deep-plowing operation.

The location of the deep-plowed block was in field B-1-3 of the Kansas State University Agronomy Farm. The location of the shallow-plowed block was in field N-2 of the KSU Agronomy Farm, after plowing the seedbed was prepared by conventional methods.

There were 6 soil-conditioner treatments plus a no-treatment check for both the shallow and deep-plowed blocks. Treatments were as follows: (1) no-treatment, (2) petro S[1/] 18.5 lbs. per acre, (3) 21.5 tons per acre manure, (4) 30 gal. per acre liquid APS[2/], (5) 8 tons gypsum per acre, (6) this plot was left unharvested in 1965 because there was no-treatment on it, (7) 21.5 tons straw per acre, (8) 21.5 tons manure per acre plus 18.5 lbs. per acre of Petro S. All treatments were applied on the surface and disked into the soil before planting.

Forty by thirty-six feet plots were planted to Greenleaf sudangrass on July 10, 1965 at the rate of 20 lbs. per acre with a standard wheat drill. Planting could not be accomplished sooner because of the wetness of the "slick-

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1/ Registered trademark of Petrochemicals Company, Inc.

2/ Allied Chemical company's Liquid Ammonium Polysulfide

EXPLANATION OF PLATE I

Two views of the deep-plowing operation. The deep-plowed block was plowed to a depth of 24 inches in the early spring of 1965.

spot" soil caused by heavy rains in early June. The area was extremely slow in drying out due to the dispersed soil condition. No fertilizer was applied in 1965.

Stand density, plant height, color, and visible physical conditions of the soil were observed, and are reported in Figure 4 and in Table 5. The crop was harvested at the end of the growing season and forage yields and protein contents determined.

Treatments were not replicated (there were three subsamples taken so table values are the average of the 3 subsamples), thus usual statistical analyses were not applicable. Estimates of the significance of plowing depths and chemical treatments were made by combining the data for the two areas and the depth and the treatment effects tested against the depth x treatment interaction.

1966 Field Experiment

This test was established on the 1965 sudangrass plots. The sudangrass was shredded with a rotary stalk chopper and disked to establish an acceptable seedbed. Ottawa wheat was planted on October 15, 1965 at the rate of $1\frac{1}{4}$ bushels per acre immediately following sudangrass harvest. All plots except the check (no-treatment plot) received the following fertilizer. Phosphorus was applied with the seed by means of a standard wheat drill at 50 lbs. of phosphorus as 45% superphosphate per acre. Nitrogen was top-dressed in the spring at 25 lbs. of N per acre as ammonium nitrate.

Plots were the same as those of the year before except that plot 6 had the above amount of fertilizer without any ameliorative treatment. The no-treatment plot received neither an ameliorative treatment nor fertilizer. A check of the benefit of fertilizer alone could be made, therefore, by comparison of the fertilizer (plot 6) treatment to the no-treatment plot. Wheat yields, test

weight, and protein content were determined in 1966 on the wheat grain.

Laboratory Investigations

Soil samples were collected in the summer of 1966 (after wheat harvest) and the following laboratory determinations were made: (1) saturation percent, (2) pH, (3) cation exchange capacity, (4) soluble cations, (5) soluble anions, (6) exchangeable cations, (7) free lime, and (8) electrical conductivity. These were made to gain information about the chemical and physical properties of the "slick-spot" soil to use as a basis for its diagnosis, treatment, and management in future years.

The saturated-soil paste was prepared by adding distilled water to the soil sample while stirring with a spatula. At saturation, the soil paste glistened as it reflected light, flowed slightly when the container was tipped, and slid from a wet spatula. From the saturated paste most of the above mentioned determinations were made. Details of these laboratory determinations follow.

(1) The saturation percentage was determined by placing a small amount of the saturated-soil paste into a tared soil-moisture can and then weighed. After drying at 105°C, it was reweighed to a constant weight. Saturation percentage = (loss in weight on drying) x 100/ (weight of the oven-dry soil).

(2) The pH readings were made on the saturated-soil paste, after one hour, with a Fisher Accumet Model 210 regular electrode pH meter.

(3) The cation-exchange capacity was determined from a 4-gram sample. The sample was placed in a 50 ml. plastic centrifuge tube with 33 ml. of 1 N sodium-acetate solution, stoppered and shaken for 5 minutes. Next the sample was centrifuged at a (Relative Centrifugal Force) RCF = 1000 until the supernatant liquid was clear. Then the supernatant liquid was decanted and

discarded. This procedure was repeated 3 additional times. The same procedure was carried out with 95% ethanol for a total of three times or until the electrical conductivity of the supernatant liquid from the last washing was less than 40 micromhos per cm. The adsorbed sodium was replaced from the sample by extraction with three-33 ml. portions of ammonium acetate and the sodium concentration of the combined extracts was determined after being brought to a volume of 100 ml.

Cation-exchange capacity in milliequivalents per 100 grams = (sodium concentration of extract in milliequivalents per liter x 10)/ (weight of sample in grams).

(4) A saturation extract was prepared by transferring the saturated soil paste to Buechner-filter funnels and applying vacuum. The extract was collected in a test tube for analysis of cations and anions.

Calcium and magnesium were analyzed by diluting the saturation extract 1 to 10 for calcium, and 1 to 20 for magnesium, and determining the amount on the Perkin-Elmer Model-303 Atomic Absorption Instrument. Sodium and potassium were analyzed on the Perkin-Elmer Flame Photometer Model 52A.

Soluble cations in milliequivalents/100 grams = (cation concentration of saturation extract in milliequivalent/l.) x (saturation percentage/1000).

(5) Carbonate and bicarbonate anions were determined by titration with acid. A small amount of the above mentioned saturation extract was pipetted into a small porcelain crucible. One drop of phenolphthalein was added and if the solution turned pink, sulfuric acid was added dropwise from a 10 ml. microburet at 5-second intervals until the pink color just disappeared. This was designated reading (b). Two drops of methyl-orange indicator were added and the extract was titrated to the first orange color. This reading was designated as (a).

Milliequivalents per liter of CO_3 = (2b x normality of H_2SO_4 x 1000)/ (ml. in aliquot). Milliequivalents per liter of HCO_3 = (a-2b) x (normality of H_2SO_4 x 1000)/ (ml. in aliquot).

The above sample also was used for the chloride determination. Four drops of 5-percent potassium chromate were added and then titrated with silver nitrate to the first permanent reddish-brown color. The titration-blank correction was 0.03.

Milliequivalents per liter of Cl. = (ml. of $AgNO_3$ - ml. of $AgNO_3$ for blank) x 0.005 x 1000/ (ml. in aliquot).

Sulfate was determined by pipetting a 20-ml. quantity of saturation extract into a 50-ml. conical centrifuge tube. Then 1 ml. of calcium chloride and 20 ml. of acetone were added, mixed and left for a few minutes to flocculate and precipitate. Next the samples were centrifuged at RCF = 1000 for 3 minutes, decanted, inverted and drained 5 minutes. Ten ml. of acetone were blown from a pipet to wash down the walls, then the centrifuge steps were repeated. After this, 40 ml. of water were added and shook to dissolve precipitate and the conductivity was measured with a standard Wheatstone-Conductivity Bridge. The concentration of $CaSO_4$ in the solution was determined by reference to a graph showing the relationship between the concentration and the electrical conductivity of the $CaSO_4$ solution. Milliequivalents per liter of SO_4 = (meq. per liter of $CaSO_4$ from electrical conductivity reading and graph) x (ml. in aliquot/ml. of water used to dissolve precipitate).

(6) Exchangeable cations were determined by first obtaining the ammonium-acetate extractable cations. Samples of soil were added to a centrifuge tube for the ammonium-acetate extractable cations. Then 33 ml. of ammonium acetate were added, shook for 5 minutes, and centrifuged for approximately 5 minutes at RCF = 1000. The clear liquid was poured into a beaker, then extracted the same

way 2 more times. The sample was diluted to a volume of 100 ml., stirred, and calcium and magnesium determined on the Perkin-Elmer Model-303 Atomic Absorption unit. Sodium and potassium were determined on the Perkin-Elmer flame photometer.

Ammonium-acetate extractable cations in milliequivalents per 100 grams = (cation concentration of extract in milliequivalents per liter x 10)/ (weight of sample in grams).

Exchangeable cations in milliequivalents per 100 grams = (extractable cations in milliequivalents per 100 grams) - (soluble cations in milliequivalents per 100 grams).

(7) Alkaline-earth carbonates were detected by adding 3 normal HCl dropwise to a small quantity of soil. A negative sign was recorded for no effervescence.

(8) Electrical conductivity was determined by the standard Wheatstone Bridge. More complete directions may be found in Handbook Number 60 (54).

RESULTS AND DISCUSSION

1965 Field Experiment

Composite soil-test data of the top six inches for the deep-plowed and the shallow-plowed blocks indicated little variation in nutrient levels, pH, and organic matter as shown in Table 1. Marked differences in conductivity, pH, total cations, and sodium percentage between the "slick-spot" and normal soil in adjacent areas are shown in Tables 1, 2, 3, 11, 12, and Figure 3. Rainfall was above average for the year as reported in Table 4. Greater differences among treatments in this experiment might have shown up had rainfall been more limiting since "slick-spot" soils are usually drouthy. Also, with less rainfall, greater differences between the shallow-plowed and the deep-plowed plots may have shown up due to the latter's greater root-penetrating depth and greater

Table 1. Composite fertility-test data for the top six inches of "slick-spot" and adjacent normal soil. (Analyzed by the KSU soil-testing lab).

Location	Organic Matter	pH	Lime require-ment	Available phosphorus	Exchangeable potassium
	%		lbs/acre	lbs/acre	lbs/acre
Shallow-plowed	1.6	7.5	-	22	344
Deep-plowed	1.4	7.7	-	19	316
Normal soil	2.1	5.8	5000-6000	11	301

Table 2. Water-soluble calcium, sodium, potassium, and magnesium of "slick-spot" and adjacent normal soil in milliequivalents per liter. (Average of all plots).1/

Soil	Depth (Inches) 0-6	12-18	24-30
	Total Soluble Salts		
	meq/1	meq/1	meq/1
Normal Soil 2/	20.5	17.6	20.7
"Slick-Spot" soil	34.8	33.5	33.9

1/ For more complete details see Table 12.

2/ Normal soil analyzed in 1935 by Ahi, (reference 1).

Table 3. Average exchangeable-cation percentages and pH values, from all plots, of "slick-spot" soil.1/

Cation	Depth (Inches)		
	0-6	12-18	24-36
	Percent		
Calcium	40.5	37.7	36.8
Magnesium	29.0	31.5	32.2
Potassium	4.6	3.3	2.7
Sodium	18.0	17.9	17.3
pH Values	8.0	8.3	8.4

1/ For more complete analysis see Table 11.

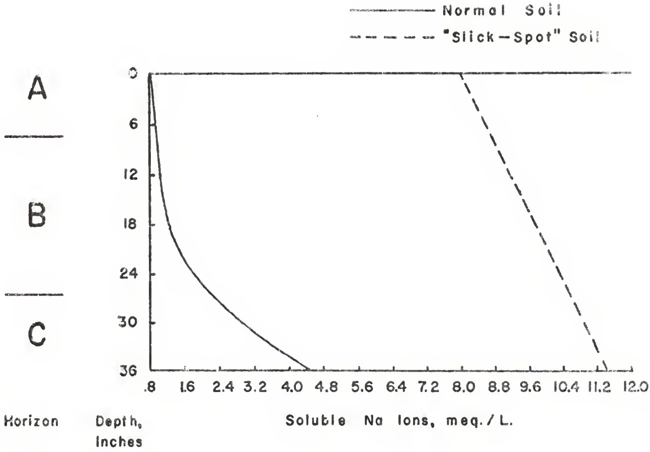

Fig. 3. Average distribution of soluble sodium in "slick-spot" and adjacent normal soil profiles.

Table 4. Monthly precipitation, Manhattan, Agronomy Farm, Manhattan, Kansas, 1965 and 1966.

Month											
Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
					1965						
1.92	1.51	2.06	1.48	1.93	11.27	3.66	2.95	8.48	1.11	.28	2.17

Yearly Total = 38.82 inches

Growing Season Total (April-Sept.) = 29.77 inches

					1966						
.40	.70	.04	1.83	1.65	1.62	2.41					

Yearly Total (Jan.-June) = 6.24 inches

Growing Season Total (Planting to Harvest) = 9.12 inches

moisture-storage capacity as shown by ease of penetration of the soil probe.

Figure 4 illustrates the differences that were found in the height of the sudangrass 55 days after planting. Sudangrass in the shallow-plowed block grew more rapidly and to a greater height than did the sudangrass in the deep-plowed block. This was attributed in part to the poor physical condition and lower nutrient availability of the soil turned up to the surface by the deep-plowing. Seedling germination was hampered by the crusted surface, causing less dense stands in the deep-plowed block. Also, the deep-plowed block was waterlogged which cut down aerobic bacterial decomposition of organic materials and subsequent release of nutrients.

The sudangrass was darker green, and grew faster and more uniformly on the gypsum-and straw-treated plots of both blocks as shown in Figure 4 and Table 5. The surface of the gypsum and straw plots of both blocks remained moist and crust free for a much longer period following precipitation than for the other treatments, as shown in Table 5 and illustrated in Plate II. In 1965 a year of excessive rainfall there was much less runoff and erosion from the gypsum and straw plots. Estimated erosion values are given in Table 5. Deep-plowing appeared to bury weed seeds, for considerably fewer weedy annual forbes and grasses occurred in the deep-plowed plots than in the shallow-plowed plots. Vigor and stand differences between the sudangrass grown on the gypsum and no-treatment plots of the shallow-plowed block are also illustrated in Plate II, and reported in Table 5.

Sudangrass-forage yields are given in Table 6 and in Figure 5 as percent of no-treatment. Yields were increased by all treatments except Liquid Ammonium Polysulfide. The treatments, manure plus Petro S and straw produced yield increases of more than a ton in the deep-plowed block. In the shallow-plowed block the above mentioned plots plus manure and gypsum also gave

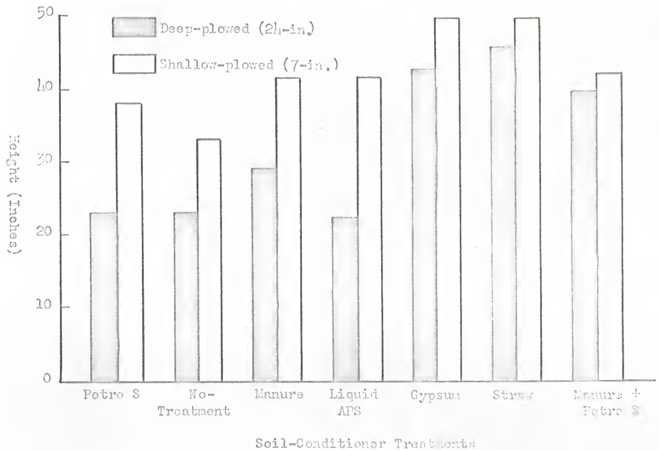

Figure 4. Height of sudangrass 55 days after planting on "slick-spot" soil as influenced by soil-conditioner treatments and plowing depth.

Table 5. Surface-crust, stand-density, color-intensity, and relative erosion data from salt-affected soil area on the KSU Agronomy farm.

Treatments	Deep-plowed				Shallow-plowed			
	Surface[1/] Crust	Stand[2/] Density	Color[3/] Intensity	Relative[4/] Erosion	Surface Crust	Stand Density	Color Intensity	Relative Erosion
1965								
Petro S	5	5	2	4	4	5	4	5
No-Treatment	5	4	3	4	4	5	4	5
Manure	4	3	2	3	3	4	3	3
Liquid APS	5	4	2	5	4	4	3	4
Gypsum	1	2	1	1	2	2	2	1
No-Treatment	3	2	2	3	3	2	3	4
Straw	1	2	2	2	2	1	2	1
Manure & Petro S	2	1	1	3	2	2	1	2
1966								
Petro S	4	4	3	1	4	4	3	1
No-Treatment	4	4	3	2	4	5	4	1
Manure	4	3	3	1	3	4	3	1
Liquid APS	4	3	2	2	4	4	3	1
Gypsum	1	1	1	1	1	1	2	1
Fertilizer-only	2	2	1	1	3	2	2	1
Straw	1	2	1	1	2	2	1	1
Manure & Petro S	1	2	1	1	2	1	1	1

1/ Rating Scale 1-5; 1 = Least crust

2/ Rating Scale 1-5; 1 = Most dense stand

3/ Rating Scale 1-5; 1 = Darkest green

4/ Rating Scale 1-5; 1 = Least erosion

EXPLANATION OF PLATE II

A comparison of the no-treatment plot (above) and the gypsum plot (below) of the shallow-plowed block, on August 5, 1965. Note the white dispersed surface of the no-treatment plot and the moist surface soil and dense stand of the gypsum-treated plot.

Table 6. Sudangrass yields on "slick-spot" soil as influenced by soil-conditioner treatments.

Treatment	Yield lbs/Acre* Plowed at 7-in. depth	Plowed at 24-in. depth	Mean
Petro S	3,100	1,840	2,470
No-Treatment	2,760	1,510	2,135
Manure	3,520	2,640	3,080
Liquid APS	3,140	1,130	2,135
Gypsum	3,580	2,520	3,050
Straw	4,270	3,620	3,945 1/
Manure + Petro S	3,540	3,950	3,745 1/
Mean	3,416	2,459	

*Calculated at 20% moisture content.
$LSD_{.05}$, Chemical Treatment = 1477
$LSD_{.05}$, Depth = NS
1/ Significant at the .05 level.

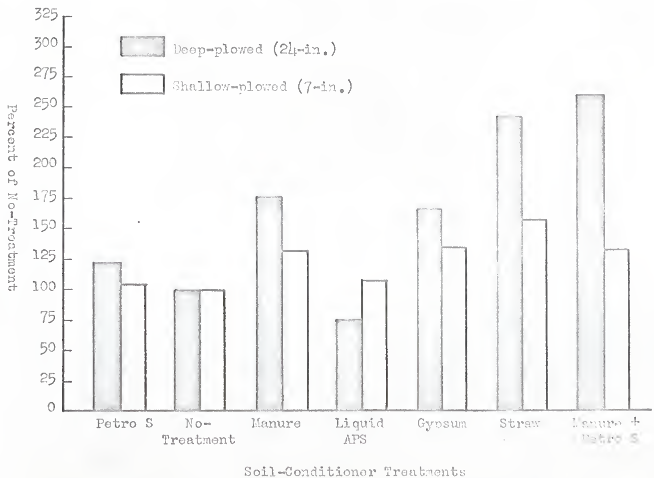

Figure 5. Sudangrass-forage yields (expressed as percent of no-treatment) from "slick-spot" soil as influenced by soil-conditioner treatments.

substantial yield increases. However, only the treatments straw and manure plus Petro S were significantly better than the no-treatment plot at the 5-percent level. The highest yield was over 2 tons of 20-percent moisture forage per acre for the straw treatment in the shallow-plowed block. The above yield data was the result of only one cutting taken in early October. Two cuttings probably could have been made had the sudangrass been planted by the first of June.

Yields as influenced by the two plowing depths are reported in Table 6, also. Except for the manure plus Petro S treatment the deep-plowed plots yielded less than the shallow-plowed plots. In the manure plus Petro S plot deep-plowing increased the yield by 11.6 percent, however, the average decrease was 29.7 percent for the deep-plowed block. As mentioned previously, this decrease was attributed to the poor seedbed of the exposed B horizon. Tillage depths were confounded because plowed plots were located in one area and the shallow-plowed plots in another. It could not be determined therefore whether differences were due to plowing or location.

Table 6, also, presents information on interaction among soil-conditioner treatments and plowing depths. Interaction differences could not be tested validly for significance either; although there are large differences.

Data on protein contents of sudangrass forage are given in Table 7. Deep-plowing appeared to increase protein content of sudangrass forage. This may have been due to the lower yields of the deep-plowed block, with the one exception of the straw plot where protein was lower than in the shallow-plowed block. The no-treatment plot in the shallow-plowed block was extremely low in protein. The reason for this is not known.

Table 7. Percentage of protein in sudangrass forage from "slick-spot" soil as affected by soil-conditioner treatment and tillage depths.

Chemical Treatment	Mechanical Treatment		
	Deep plowed	Normal plowed	Mean
Petro S	8.2	7.8	8.0
No-treatment	8.0	6.0	7.0
Manure	9.7	9.8	9.8
Liquid APS	9.8	8.2	9.0
Gypsum	7.4	7.8	7.6
Straw	7.0	9.0	8.0
Manure + Petro S	10.5	9.7	10.1
Mean	8.6	8.3	8.5

$LSD_{.05}$, chemical treatment = NS
$LSD_{.05}$, depth NS

1966 Field Experiment

The only change in the experimental design in 1966 from that of 1965 was the addition of a fertilizer-only treatment, so that influence of 50 pounds of phosphorus and 25 pounds of N could be compared. No soil-conditioner amendments were added to the respective plots in 1966, so that carryover effects could be compared.

Wheat-grain yield information is reported in Table 8 and Figure 6. Table 4 shows 1966 was a drier year and so greater yield differences were noted among treatments in the shallow-plowed plots.

The greatest percentage increase was shown with the gypsum treatment. In 1965 Sudangrass yields were increased 30 percent over the no-treatment plot, whereas wheat-grain yields were increased 224 percent in 1966 with the gypsum treatment. For other comparisons see Figures 5 and 6. All soil-conditioner treatments increased wheat-grain yields on the shallow-plowed plots. However, Petro S, manure, and Liquid Ammonium Polysulfide decreased yields in the deep-plowed plots. There were no obvious explanations for this, but many factors could contribute to the decrease. Plots were chosen at random, however the three plots that decreased yields mentioned above were observed to have less favorable soil-physical conditions at the beginning of the test than most of the other plots (Table 5). Table 5 showed that a slight improvement was made in physical conditions of the soil in most plots over the two-year period. Although the Petro S, manure, and Liquid Ammonium Polysulfide plots gave lower yields than the no-treatment plot, these yields were higher than the yields for corresponding shallow-plowed plots, a sharp contrast from the previous year's data.

Yields were quite uniform in the deep-plowed block with wheat yields on

Table 8. Wheat-grain yields on "slick-spot" soil as influenced by soil-conditioner treatments.

Treatment	Yield Bus./Acre*		
	Plowed at 7-in. depth	Plowed at 24-in. depth	Mean
Petro S	10.11	11.70	10.92
No-treatment	5.58	13.00	9.29
Manure	8.29	11.77	10.03
Liquid APS	7.54	10.11	8.83
Gypsum	18.10	17.20	17.65 1/
Fertilizer Only	11.76	15.84	13.80 1/
Straw	12.97	15.68	14.33 1/
Manure + Petro S	15.08	13.86	14.47 1/
Mean	11.18	13.58	

*Calculated at 12.5% moisture.
$LSD_{.05}$, Depth = NS
$LSD_{.05}$, Chemical treatment = 4.16
1/ Significant at the .05 level

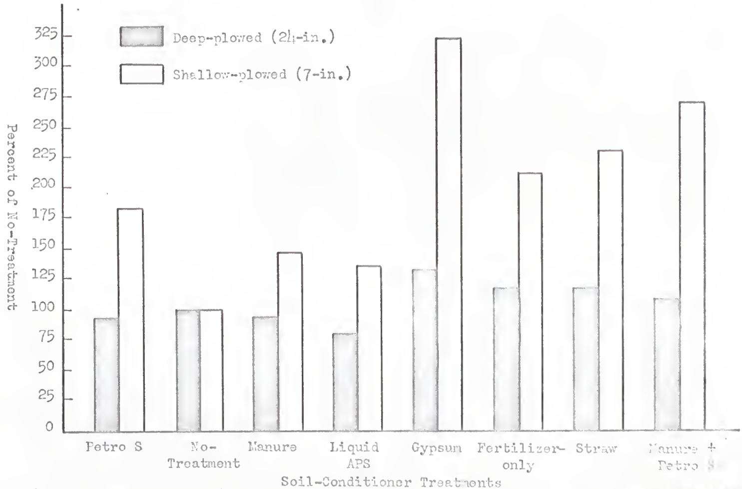

Figure 6. Wheat-grain yields (expressed as percent of no-treatment) from "slick-spot" soil as influenced by soil-conditioner treatments and plowing depth.

the gypsum-treated plot slightly the best. Wheat on the gypsum plot germinated more rapidly and grew faster all through the season as shown in Plate III.

Some sizable yield increases occurred with different treatments in the shallow-plowed block, the greatest being the gypsum treatment with a 224 percent yield increase over the no-treatment yield. The gypsum plot yielded 18.1 bushels per acre, which was only about 1 bushel below the normal-soil yields on the Kansas State University Agronomy Farm for 1966. Also, wheat was planted immediately after disking in the sudangrass, so top yields could not be expected.

At the 5-percent level the following treatments significantly increased yields over the check: gypsum, fertilizer-only, straw, and manure plus Petro S. The gypsum treatment gave higher wheat yields than other treatments.

Interaction of plowing depths and soil-conditioner treatments on wheat-grain yields are also presented in Table 8.

The effects of plowing depths on wheat-grain yields are reported in Table 8, also. All treatments except gypsum, and manure plus Petro S increased yields in the deep-plowed block in comparison to the yields obtained from their shallow-plowed counterparts. The 33.4 percent average increase for all treatments in the deep-plowed block over the shallow-plowed block was in sharp contrast to the 1965 results which averaged 29.7 percent decrease. As this was the second crop to be grown, the physical condition of the deep-plowed soil was improved and better stands were obtained. The year 1966 was drier than 1965, making moisture more limiting to crop growth and giving a corresponding advantage to the deep-rooting zone of the deep-plowed plots. Difference in rooting-zone depths of the shallow-plowed plots was readily demonstrated by probing with a truck-mounted soil probe. The probe penetrated past three feet in the deep-plowed plots, but only to a depth of about two feet in the

EXPLANATION OF PLATE III

A comparison of wheat growing on a no-treatment plot (above) and a gypsum-treated plot (below) of the deep-plowed block on March 15, 1966. Note the differences in stand and stage of growth.

shallow-plowed block.

The no-treatment plot in the deep-plowed block increased wheat yields 133 percent over the corresponding plot in the shallow-plowed block. This indicates that deep-plowing alone increased wheat-grain yields. However, due to the layout of the experiment no valid significance could be placed on the differences observed from the different plowing depths. Explanation of the experimental layout is explained in the discussion of the experimental procedure. The 1966 wheat yields indicated that substantial yield increases can be obtained when some soil-conditioner treatments are applied in combination with deep-plowing. Fertilizer-only increased yields, however, gypsum, straw, and manure plus Petro S increased yields even more.

Wheat test-weight data are included in Table 9. Test weights averaged about 60 pounds per bushel. Wheat from the shallow-plowed block had a higher test weight than wheat from the deep-plowed block.

Wheat-grain protein data are presented in Table 10. Percent protein was average to high in all cases. In the shallow-plowed block all treatments except gypsum produced wheat with higher protein content than the no-treatment plot.

In the deep-plowed block all treatments produced wheat with higher protein content than the no-treatment plot.

Laboratory Investigations

Laboratory analyses were made on the soils to characterize chemical properties and to classify the soil.

In the deep-plowed plots the saturation percentage varied from 39 to 64 percent, whereas the shallow-plowed plots varied from 39 to 65 percent as shown in Table 11. The saturation percentage went up with depth, and generally was

Table 9. Wheat test weights on "slick-spot" soil.

Treatment	Shallow-plowed	Deep-plowed	Average
Petro S	59.5	58.2	58.8
No-treatment	61.0	59.7	60.4
Manure	59.4	57.5	58.4
Liquid APS[1/]	59.7	59.0	59.4
Gypsum	61.5	59.9	60.7
Fertilizer-Only	59.9	59.4	59.6
Straw	59.7	59.4	59.6
Manure + Petro S	61.2	58.6	59.9

$LSD_{.05}$, Chemical Treatment = NS
$LSD_{.05}$, Depth = NS
[1/] Liquid Ammonium Polysulfide

Table 10. Percent protein of wheat grain from "slick-spot" soil.

Treatment	Shallow-plowed	Deep-plowed	Average
Petro S	14.6	16.5	15.8
No-treatment	14.6	14.6	14.6
Manure	17.2	18.0	17.6
Liquid APS	15.1	17.3	16.2
Gypsum	14.4	15.4	14.9
Fertilizer-Only	17.7	16.0	16.8
Straw	17.7	16.0	16.8
Manure + Petro S	15.7	17.6	16.6

$LSD_{.05}$, Chemical Treatment = NS
$LSD_{.05}$, Depth = NS

Table 11a. Saturation percentage, pH, cation-exchange capacity, exchangeable-cation percentages and alkaline-earth carbonates for the 0 to 6-, 12 to 18-, and 24 to 30-inch depths of the deep-plowed soil. Samples were taken after two crop years.

Soil Sample			Saturation Percentage	pH of Sat'd Soil	Cation-Exchange Capacity meq/100 g	Exchangeable-Cation Percentages				Alkaline-Earth Carbonates[2]
Treatment number	Plot	Depth[1]				Na	K	Ca	Mg	
1	Petro S	1	55.00	7.7	30.0	19.4	5.0	34.0	32.8	-
	"	2	60.50	8.5	34.0	19.0	3.6	36.0	30.0	+
	"	3	60.08	8.3	32.0	15.0	2.7	38.0	33.0	+
2	No-	1	57.00	8.4	31.0	20.2	3.0	35.0	33.0	+
	Treat-	2	64.00	8.4	35.5	20.6	3.1	34.0	34.0	+
	ment	3	63.88	8.5	34.5	16.9	4.9	38.0	30.1	+
3	Manure	1	54.60	8.3	30.9	20.8	6.2	38.0	27.0	+
	"	2	59.11	8.4	31.5	19.5	2.9	36.0	31.9	+
	"	3	61.56	8.5	32.3	17.2	2.1	33.8	34.5	+
4	Liquid	1	47.00	8.5	31.0	15.0	4.0	38.0	32.7	+
	APS	2	46.00	8.4	30.2	19.9	2.7	32.8	34.0	+
	"	3	44.83	8.5	30.0	22.0	1.8	30.0	32.8	+
5	Gypsum	1	44.00	8.0	37.0	4.0	4.4	49.0	34.0	+
	"	2	43.00	8.0	36.0	14.0	2.6	43.0	32.6	+
	"	3	45.00	8.4	35.5	14.7	3.1	40.0	34.0	+
6	Ferti-	1	40.60	7.6	30.0	18.0	4.6	42.5	23.6	-
	lizer-	2	39.00	7.8	29.5	17.0	3.4	39.0	32.0	+
	only	3	49.78	8.3	35.0	17.8	2.4	38.0	31.0	+
7	Straw	1	44.06	8.2	31.0	18.8	6.0	43.5	22.0	+
	"	2	53.97	8.4	37.0	18.4	4.0	37.6	30.2	+
	"	3	54.00	8.4	36.5	17.1	2.8	40.0	31.0	+
8	Manure	1	42.70	7.4	31.0	17.0	4.0	44.0	26.7	-
	Plus	2	47.17	8.3	33.0	15.4	3.8	43.0	28.0	+
	Potro S	3	53.24	8.4	34.0	17.8	3.0	36.6	34.0	+
Average			51.25	8.2	32.3	17.3	3.5	38.3	31.0	

1/Depth 1 = 0 to 6 in., 2 = 12 to 18 in., 3 = 24 to 30 in.
2/- absont, + prosont

Table 11b. Saturation percentage, pH, cation-exchange capacity, exchangeable-cation percentages and alkaline-earth carbonates for the 0 to 6-, 12 to 18-, 24 - 30-inch depths of the shallow-plowed soil. Samples were taken after two crop years.

Soil Sample			Saturation Percentage	pH of Sat'd Soil	Cation-Exchange Capacity meq/100 g	Exchangeable-Cation Percentages				Alkaline-Earth Carbonates 2/
Treat-ment number	Plot	Depth 1/				Na	K	Ca	Mg	
1	Petro S	1	50.19	7.7	30.0	14.8	3.4	36.0	33.9	-
	"	2	61.15	8.2	35.0	17.1	3.8	34.0	37.0	+
	"	3	57.45	8.2	34.0	16.8	2.8	38.1	30.6	+
2	No-	1	54.04	7.5	32.0	16.9	3.3	37.0	34.6	-
	Treat-	2	48.78	8.0	29.5	17.0	3.7	38.5	30.6	+
	ment	3	53.76	8.1	31.5	16.6	3.7	37.0	31.8	+
3	Manure	1	55.37	7.5	32.0	17.5	4.1	33.0	36.0	-
	"	2	40.23	7.9	28.0	18.4	2.2	37.8	29.9	+
	"	3	50.94	8.2	30.0	18.5	4.0	38.6	30.0	+
4	Liquid	1	58.44	7.3	34.0	16.2	3.5	37.0	33.3	-
	APS	2	46.88	7.8	29.0	19.8	2.1	36.0	32.0	+
	"	3	60.90	8.2	34.5	21.7	1.8	36.0	30.8	+
5	Gypsum	1	40.63	7.2	27.5	17.0	3.7	34.9	33.1	-
	"	2	47.62	7.6	30.0	16.0	2.1	38.5	33.3	-
	"	3	64.00	8.2	36.5	18.3	3.4	38.0	30.9	+
6	Ferti-	1	40.41	7.7	28.0	15.0	3.8	37.0	35.2	-
	lizer-	2	60.39	8.3	34.0	15.6	1.0	41.5	30.9	+
	only	3	65.18	8.4	37.0	15.6	3.2	36.0	36.8	+
7	Straw	1	39.14	7.4	27.5	16.9	3.9	37.5	30.6	-
	"	2	43.98	8.3	29.0	15.4	3.9	38.7	31.4	+
	"	3	58.17	8.4	35.0	17.1	2.1	37.0	33.9	+
8	Manure	1	63.00	7.5	36.0	12.2	4.8	44.0	29.0	-
	Plus	2	62.30	7.9	35.5	14.3	2.4	41.8	32.8	+
	Petro S	3	62.56	8.1	38.5	16.6	3.4	38.1	31.9	+
Average			53.56	7.9	32.2	16.7	3.2	37.0	32.5	
Test Average			52.04	8.1	32.5	17.0	3.4	38.0	31.8	

1/Depth 1 = 0 to 6 in., 2 = 12 to 18 in., 3 = 24 to 30 in.
2/- absent, + present

higher for the shallow-plowed plots. Average values were 51 percent for the deep-plowed and 54 percent for the shallow-plowed block.

Values for pH ranged from 7.4 to 8.5 in the deep-plowed block and from 7.2 to 8.4 for the shallow-plowed block as reported in Table 11. The pH increased with depth in both blocks. In the shallow-plowed block all surface samples tested below 8.0, however in the deep-plowed block all plots tested above 8.0 except plots 1, 6, and 8.

The cation-exchange capacity ranged from 27.5 to 38.5 milliequivalents per 100 grams, and generally increased with depth. The average cation-exchange capacity for the deep-plowed and shallow-plowed blocks was 32.8 and 32.7, respectively, also reported in Table 11.

Alkaline-earth carbonates (free lime) were present in all 24 to 30-inch depth samples and all the 12 to 18-inch depth samples but the gypsum-treated plot in the shallow-plowed block. Free lime was also found in the 0 to 6-inch depth samples for plots 2, 3, 4, 5, and 7 (Table 11).

All plots in the deep-plowed except the 3 depths for the gypsum plot had 15 percent or more exchangeable sodium. The range for the deep-plowed block was 4.0 to 22.0 percent. The range in the shallow-plowed block was 12.2 to 21.8 percent. In the shallow-plowed block only the surface soil of the Petro S and the first two depths of the manure plus Petro S treated plots contained less than 15.0 percent exchangeable sodium. All exchangeable cation data are also reported in Table 11.

The highest average sodium percent was found in plot 2 (no-treatment) for the deep-plowed block and in plot 4 (Liquid Ammonium Polysulfate) for the shallow-plowed block. Sodium percent normally increased with depth in the shallow-plowed block but showed no such relationship in the deep-plowed block, due to mixing of the soil in the deep-plowing process.

There was, in general, an inverse relationship between sodium and potassium amounts. As sodium increased potassium decreased. Potassium ranged from 1.0 percent for the shallow-plowed fertilizer-only (treatment 6) plot at the 12 to 18-inch depth, to a high of 6.2 percent for the deep-plowed manure (treatment 3) plot at the 0 to 6-inch depth.

The exchangeable cations, calcium and magnesium, made up from 2/3 to 3/4 of the cation percentages. Calcium ranged from 33.0 to 44.9 percent in the shallow-plowed block. In the deep-plowed block the range was 30.0 to 49.0 percent. Magnesium varied from 22.0 to 34.5 percent in the deep-plowed block, and from 29.0 to 37.0 percent in the shallow-plowed block, as shown in Table 11.

The gypsum-treated plot (treatment 5) was considerably higher in calcium than any other plot in the deep-plowed block, whereas in the shallow-plowed block all treatments were similar in calcium content. This was attributed to sodium replacement by calcium with subsequent deeper leaching of sodium in the deep-plowed block.

Table 12 contains the saturation-extract determinations. The electrical conductivity ranged from 1.16 to 2.65 millimhos per centimeter, considerably below 4.0, the minimum for a saline soil. In most cases the surface layer of the deep-plowed soil was higher in electrical conductivity. This probably was due to the placement on the surface of the high-base subsoil.

The soluble cations (calcium, magnesium, sodium, and potassium) and anions (carbonates, bicarbonates, sulfates, and chlorides) are also reported in Table 12. Soluble calcium varied from 0.3 milliequivalents per liter for the 24 to 30-inch depth of the Liquid Ammonium Polysulfide-treated plot to 7.9 milliequivalents per liter for surface soil in the manure plus Petro S-treated plot of the deep-plowed block. In the deep-plowed block the Liquid Ammonium Polysulfide plot averaged 1.2 milliequivalents per liter throughout the profile

Table 12a. Electrical conductivity, soluble cations and anions for the 0 to 6-, 12 to 18-, and 24 to 30-inch depths of the deep-plowed soil. Samples were taken after two crop years.

Soil Sample			Electrical Conductivity	Cations meq/1					Anions meq/1				
Treat-ment number	Plot	Depth[1]	mmhos/cm	Ca	Mg	Na	K	Total	CO_3	HCO_3	SO_4	C_1	Total
1	Petro S	1	1.49	2.86	2.90	8.97	.89	15.62	0	5.5	2.5	8	16.0
	"	2	1.57	3.89	1.98	9.49	.89	16.25	0	7.5	2.3	7	16.8
	"	3	1.49	3.36	2.93	8.53	.48	15.30	0	7.0	2.8	6	15.8
2	No-Treat-ment	1	2.15	2.44	2.38	13.00	.45	18.27	0	4.0	7.0	9	20.0
		2	2.09	2.22	2.28	13.33	.52	18.35	0	4.9	6.0	8	18.9
		3	2.08	2.98	1.88	9.90	.87	15.63	0	4.8	5.0	6	15.8
3	Manure	1	2.08	2.95	1.65	16.00	2.03	22.63	0	6.9	2.0	13	21.9
	"	2	1.96	1.76	1.46	12.71	.46	16.39	0	5.9	2.0	9	16.9
	"	3	1.36	3.06	2.20	8.95	.36	14.97	0	5.5	1.3	8	14.8
4	Liquid APS	1	1.62	2.40	1.80	10.20	.60	15.00	0	3.9	2.0	9	14.9
		2	1.91	.95	1.26	14.90	.42	17.53	0	5.0	3.0	10	18.0
	"	3	1.77	.30	1.13	15.00	.26	16.69	0	6.2	1.5	8	15.7
5	Gypsum	1	1.97	7.40	3.80	5.53	1.00	17.73	0	3.2	7.0	8	18.2
	"	2	2.20	6.46	2.77	8.41	.49	18.13	0	2.8	7.9	8	18.7
	"	3	1.68	4.90	2.95	8.89	.38	17.12	0	5.5	4.7	8	18.2
6	Ferti-lizer-only	1	2.50	5.74	1.83	10.83	.90	19.30	0	2.8	3.8	12	18.6
		2	1.69	2.88	1.66	8.89	.57	14.00	0	3.2	3.0	8	14.2
		3	1.39	2.00	1.59	10.83	.42	14.84	0	5.0	1.3	9	15.3
7	Straw	1	2.65	6.80	1.83	13.05	1.90	23.58	0	5.5	3.3	14	22.8
	"	2	1.80	3.88	2.76	10.73	.85	18.22	0	7.0	3.0	9	19.0
	"	3	1.72	4.40	2.98	9.88	.48	17.74	0	6.9	2.5	9	18.4
8	Manure Plus Petro S	1	2.36	7.90	1.83	9.30	1.20	20.23	0	3.2	2.3	14	19.5
		2	1.87	7.43	1.97	7.68	.73	17.81	0	4.6	1.8	11	17.4
		3	1.59	3.21	2.72	9.11	.52	15.56	0	6.3	1.3	9	16.6
Average			1.87	3.84	2.19	10.59	.74	17.36	0	5.13	3.30	9.17	17.60

[1] Depth 1 = 0 to 6 in., 2 = 12 to 18 in., 3 = 24 to 30 in.

Table 12b. Electrical conductivity, soluble cations and anions for the 0 to 6-, 12 to 18-, and 24 to 30-inch depths of the shallow-plowed soil. Samples were taken after two crop years.

Soil Sample			Electrical Conductivity	Cations meq/1					Anions meq/1				
Treatment number	Plot	Depth 1/	mmhos/cm	Ca	Mg	Na	K	Total	CO_3	HCO_3	SO_4	C_1	Total
1	Petro S	1	1.25	1.99	1.93	8.11	.56	12.59	0	3.7	.8	8	12.5
	"	2	1.66	2.31	2.99	10.82	.68	16.80	0	5.0	2.3	10	17.3
	"	3	1.56	3.95	2.50	9.93	.56	16.94	0	4.3	3.0	9	16.3
2	No-Treatment	1	1.65	3.08	2.70	9.88	.56	17.22	0	4.2	1.8	10	16.0
		2	1.66	4.00	2.08	10.64	.62	17.34	0	4.6	2.3	10	16.9
		3	1.77	3.89	2.96	9.86	.60	17.31	0	4.6	3.9	9	17.5
3	Manure	1	1.81	3.54	3.86	10.00	.88	18.28	0	2.7	6.3	11	20.0
	"	2	2.05	3.00	1.74	11.91	.42	17.07	0	4.6	4.0	10	18.6
	"	3	1.40	4.10	2.96	12.00	1.05	20.11	0	4.8	2.2	11	18.0
4	Liquid APS	1	1.40	3.02	2.08	9.20	.90	15.20	0	2.8	1.3	11	15.1
		2	1.60	2.61	1.75	14.24	.40	19.00	0	4.8	1.7	11	17.5
	"	3	2.15	2.56	1.74	17.00	.45	21.75	0	5.9	4.0	11	20.9
5	Gypsum	1	2.19	3.00	2.70	11.40	.90	18.00	0	3.0	2.4	11	16.4
	"	2	1.59	2.88	1.68	9.91	.47	14.94	0	2.8	1.8	10	14.6
	"	3	1.41	3.64	1.92	12.04	.82	18.42	0	4.6	1.2	12	17.8
6	Fertilizer-only	1	1.29	2.00	1.76	8.28	.86	12.90	0	1.8	1.5	10	13.3
		2	1.49	3.00	1.71	9.52	.26	14.49	0	4.8	1.8	8	14.6
		3	1.16	1.90	1.99	9.28	.63	13.80	0	4.3	1.0	8	13.3
7	Straw	1	2.20	4.38	2.00	10.78	1.00	18.16	0	2.8	2.5	12	17.3
	"	2	1.83	3.27	1.97	8.88	.88	15.00	0	4.6	2.3	10	16.9
	"	3	1.45	3.81	2.68	11.65	.46	18.60	0	3.9	2.9	11	17.8
8	Manure Plus Petro S	1	1.52	6.00	2.20	6.39	1.71	16.30	0	1.4	2.3	11	14.7
		2	1.28	3.99	1.85	7.90	.51	14.25	0	2.3	2.3	10	14.6
		3	1.40	3.94	2.99	10.61	.86	18.40	0	3.9	2.8	11	17.7
Average			1.62	3.33	2.28	10.43	.71	16.75	0	3.84	2.43	10.21	16.48
Test Average			1.74	3.58	2.24	10.51	.72	17.06	0	4.18	2.86	9.60	17.04

1/ Depth 1 = 0 to 6in., 2 = 12 to 18 in., 3 = 24 to 30 in.

whereas plot 5 (gypsum) averaged 6.3 milliequivalents per liter.

Soluble magnesium averaged slightly lower than calcium ranging from 1.13 to 3.86 milliequivalents per liter on the deep-plowed and shallow-plowed blocks respectively. Magnesium varied less between plots and depths than calcium.

Soluble sodium varied from 5.53 milliequivalents per liter on the deep-plowed gypsum plot at the 0 to 6-inch depth to a high of 17.00 milliequivalents per liter for the Liquid Ammonium Polysulfide plot at the 24 to 30-inch depth of the shallow-plowed block. In the shallow-plowed block sodium tended to increase with depth. In the deep-plowed block, however, sodium was highest in the surface soil, due to the turned up subsoil. Sodium was lower in the surface soil of the gypsum and polysulfide plots, which was attributed to exchange of sodium by calcium caused by those amendments.

Soluble potassium was usually highest in the surface soil, averaging around 1.0 milliequivalent per liter. For all depths potassium ranged from .26 to 2.06 milliequivalents per liter with a mean of 0.72 milliequivalents per liter, also reported in Table 12.

No carbonates occurred, as confirmed by the low pH and bicarbonate content. Bicarbonates ranged from 1.4 milliequivalents per liter in the shallow-plowed surface soil of the manure plus Petro-S plot, to 7.5 milliequivalents per liter for the 12 to 18-inch depth in the deep-plowed Petro S plot. There were less bicarbonates in the shallow-plots than the deep-plowed plots. In general, bicarbonates increased with depth (Table 12).

Sulfate content values, in general were lower than bicarbonates. Sulfates were lower in the surface layers in the shallow-plowed block, with one exception. The highest sulfate value was 7.9 milliequivalents per liter on the deep-plowed gypsum plot at a depth of 12 to 18-inches. The lowest reading was 0.8 milliequivalent per liter for the Petro S plot, surface soil, in the shallow-plowed

block, reported in Table 12.

The chloride anion averaged around 9 milliequivalents per liter for the deep-plowed plots, whereas the shallow-plowed plots averaged over 10. Chlorides ranged from 6 to 14 milliequivalents in the deep-plowed block and 8 to 14 in the shallow-plowed block as shown in Table 12.

The plots also contained soils having morphological or structural differences from normal soil and from plot to plot. In general, the soils are dispersed and have either characteristic prismatic or columnar B horizons. This striking structural profile is most common in the "Solonetz" soil. The pH indicates that leaching has caused solodization, forming the intergrade soil, solodized-Solonetz (55). The soils of this study have the well-developed structural and textural profiles and the leached A horizon of the Soloth and the nonacid columner B horizon of the Solonetz.

The soils of the experimental plots are probably Typic Natrustolls in the new comprehensive system of soil-classification. They are not quite wet enough to be classified as Natraquolls. They also resemble a ruptic intergrade with the Natralbolls.

SUMMARY AND CONCLUSIONS

A field study was conducted in 1965 and 1966 to determine the effects of several organic and chemical soil-conditioning treatments and two tillage depths upon crop yields on an alkali-affected soil. In evaluating the results of the organic and chemical materials in this study, it must be kept in mind that these data are drawn from an experiment on a soil with extremely poor physical conditions. Low crop yields have characterized these "slick-spots" prior to this experiment.

Soil treatments included: no-treatment, 18.5 lbs/acre of Petro S, 21.5

tons/acre of gypsum, 21.5 tons/acre of straw, and a combination of 21.5 tons/acre of manure plus 18.5 lbs/acre of Petro S. In the 1966 experiment a fertilizer treatmont of 50 pounds of phosphorus and 25 pounds of N was added so the benefit, if any, from fertilizer could be determined.

In 1965 all soil-conditioner treatments except liquid ammonium polysulfide increased sudangrass yields. However, only straw and manure plus Petro S significantly increased yields over the check. The highest yield was ovor 2 tons of 20-percent moisture forage per acre for the straw treatment in the shallow-plowed (normal 7-inch depth) block. In 1965, a relatively wet year, the (convontionally) shallow-plowed plots outyielded the deop-plowed plots. The highost yield from the deep-plowed block was from the manure plus Petro S plots.

In 1966 all treatments increased wheat-grain yields in the shallow-plowed block. Petro S, manure and liquid ammonium polysulfide decreased yields on the deep-plowed plots. Gypsum and Manure plus Petro S gave the highest yields in the shallow-plowed block and gypsum and the fertilizer treatment in the deep-plowed block. It is worth noting that the gypsum-plot yield of 18.1 bushels per acre was only about 1 bushel below the wheat yield of the nearby normal soil.

In 1966, a sharp contrast to 1965, yields in the deep-plowed block averaged 33.4 percent above the shallow-plowed block. However, gypsum and manure plus Petro S had slight decreases with deep-plowing. The wheat yields of the no-treatment plot in the deep-plowed block were 133 percent higher than the corresponding plot of the shallow-plowed block.

The saturation percent of these problem soils increased with depth and generally was higher for the shallow-plowed plots. The pH value increased with depth in both blocks. In the shallow-plowed block all surface samples had a pH

below 8.0; however, in the deep-plowed block all but three surface samples tested above 8.0 due to the turning up of subsurface soil.

The cation exchange capacity generally increased with depth. Free lime occurred in most subsurface samples and some surface samples.

The most significant finding was that all soils had 15 percent or greater exchangeable sodium except the gypsum plot. It was impossible to tell for certain whether the soil in the gypsum plot was lower in sodium due to the gypsum treatment or whether it was lower at the beginning of the test, since soil samples were taken after the treatments had been applied for a year. However, total base cations are lower and calcium does not make up a greater proportion of the cations in the gypsum-treated plot in comparison to all the other treatments, this would indicate that the gypsum plot was probably already somewhat lower than some of the other plots.

Potassium was low in all samples. The exchangeable cations, calcium and magnesium, made up from 2/3 to 3/4 of the cation percentages. Calcium was generally slightly higher than magnesium. Calcium and magnesium values went up as sodium and potassium went down.

Electrical conductivity was well below 4.0 millimhos per centimeter in all samples, making the soil non-saline. The lack of obvious soluble salts and the dispersed field condition confirms this analysis.

The soluble cations and anions varied in amount. Soluble magnesium averaged slightly lower than calcium, 2.2 to 3.6 respectively. Magnesium varied less with depth and from plot to plot than calcium.

Sodium tended to increase with depth in the shallow-plowed block. Deep-plowing, however, caused sodium to be highest in the surface soil. The gypsum- and polysulfide-treated plots had lower sodium and higher calcium which was attributed to sodium replacement by calcium brought about by those treatments.

Measurable quantities of carbonates did not occur. Bicarbonates ranged from 1.4 to 7.5 milliequivalents per liter, and in general increased with depth. Sulfate values were slightly lower than the bicarbonates. Chloride made up the largest part of the anions, averaging about 10 milliequivalents per liter.

Classifying these soil samples in terms of their salinity and alkalinity was somewhat difficult due to the variations that occurred. However, most of the soil samples taken were in a transition or degraded stage of a nonsaline-alkali soil.

Forty two of the classified soil horizons fell in the category of nonsaline alkali. The remaining six were normal according to the United States Salinity Laboratory chemical classification system (54).

Morphologically or genetically speaking, these soils are transitional between Solonetz and solodized-Solonetz.

Based on the results of this study it was concluded that:

1) Organic treatments, straw and manure, will increase yields on "slick-spot" soils, but these materials must be added often and at high rates to obtain maximum benefit.

2) Addition of gypsum gave increased yields, especially in the second year.

3) Gypsum improved the physical condition and tilth of the surface soil.

4) Deep-plowing appeared to increase yields from "slick-spot" soil over normal or shallow-plowing after the first year.

5) Fertilizer alone gave good results in 1966 on "slick-spot" soils that had been deep-plowed.

6) The "slick-spot" soils in question fit the category of nonsaline-alkali soil more closely than any other.

7) These are solodized-Solonetz soils, according to the early United

States system of classification.

8) These soils are Typic Natrustolls under the present system of classification.

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THE IMPROVEMENT AND MANAGEMENT OF "SLICK SPOT" SOIL

by

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A field study was conducted in 1965 and 1966 to determine the effects of several organic and chemical soil-conditioning treatments and two tillage depths upon crop yields grown on an alkali-affected (slick-spot) soil. Low crop yields have characterized these "slick-spots" prior to this experiment.

Soil treatments included: no-treatment, 18.5 lbs/acre of Petro S, 21.5 tons/acre of manure, 30 gal./acre of Liquid Ammonium Polysulfide, 8 tons/acre of gypsum, 21.5 tons/acre of straw, and a combination of 21.5 tons/acre of manure plus 18.5 lbs. of Petro S per acre. In the 1966 experiment a fertilizer treatment was added so the benefit, if any, from fertilizer could be checked.

In 1965 all soil-conditioner treatments except Liquid Ammonium Polysulfide increased sudangrass yields. The highest yield was over 2 tons of 20-percent moisture forage per acre for the straw treatment in the shallow-plowed (normal 7-inch depth) block. In 1965, a relatively wet year, the conventionally plowed plots out-yielded the deep-plowed plots. The highest yield from the deep-plowed (24-inch depth) block was from the manure plus Petro S plots.

In 1966 all treatments increased wheat-grain yields in the shallow-plowed block. Petro S, manure and Liquid Ammonium Polysulfide decreased yields on the deep-plowed plots. Gypsum and manure plus Petro S gave the highest yields in the shallow-plowed block and gypsum and the fertilizer treatment in the deep-plowed block. It was worth noting that the gypsum-plot yield of 18.1 bushels per acre was only about 1 bushel below the wheat yield of the nearby normal soil.

In 1966, in sharp contrast to 1965, yields in the deep-plowed block averaged 33.4 percent above the shallow-plowed block. The wheat yields of the no-treatment plot in the deep-plowed block were 133 percent higher than the corresponding plot of the shallow-plowed block.

The saturation percent of these problem soils increased with depth and generally was higher for the shallow-plowed plots. The pH value increased with depth in both blocks. In the shallow-plowed block all surface samples had a pH below 8.0; however, in the deep-plowed block all but three surface samples tested above 8.0 due to the turning up of subsurface soil. The cation-exchange capacity generally increased with depth. Free lime occurred in most subsurface samples and some surface samples.

The most significant finding was that all soils had 15 percent or greater exchangeable sodium except the gypsum plot. Potassium was low in all samples. The exchangeable cations, calcium and magnesium, made up from 2/3 to 3/4 of the cation percentages. Calcium was generally slightly higher than magnesium. Calcium and magnesium values went up as sodium and potassium went down.

Electrical conductivity was well below 4.0 millimhos per centimeter making the soil non-saline. The lack of obvious soluble salts and the dispersed field condition confirms this analysis.

The soluble cations and anions varied in amount. Soluble magnesium averaged slightly lower than calcium, 2.24 to 3.58 respectively. Magnesium varied less with depth and from plot to plot than calcium.

Sodium tended to increase with depth in the shallow-plowed block. Deep-plowing, however, caused the surface soil to be highest in the deep-plowed plots. The gypsum- and polysulfide-treated plots had lower sodium and higher calcium which was attributed to sodium replacement by calcium brought about by those treatments.

There were no carbonates in any sample. Bicarbonates ranged from 1.4 to 7.5 milliequivalents per liter, and in general increased with depth. Sulfate values were slightly lower than the bicarbonates. Chloride made up the largest part of the anions, averaging about 10 milliequivalents per liter.

Classifying those soil samples in terms of their salinity and alkalinity was somewhat difficult due to the variations that occurred. However, most of the soil samples taken were in a transition or degraded stage of a non-saline-alkali soil.

Morphologically, the soils were in a transition stage between a Solonetz and a solodized-Solonetz. In the new soil classification system this soil would be a Typic Natrustoll.